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Relationship between the North Atlantic Oscillation Index and October-December Rainfall Variability Over Kenya

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Abstract

Rainfall performance and variability are the major problems that affect many socio-economic activities in Kenya. This study investigates the relationship between the North Atlantic Ocean Oscillation (NAO) Index and October – December (OND) rainfall variability over Kenya. Rainfall, wind, geopotential height, temperature, moiture transport and NAO Index (NAOI) values for the period 1961 - 2010 are investigated. The region experiences rainfall that is highly variable in space and time; with the country generally experiencing bimodal rainfall. There is an insignificant negative correlation between the OND rainfall and NAOI over most parts of the country except for the Lake Victoria region that experiences significant correlation at 90% significance level. The study recommends further research on how the NAOI can be used as a predictor for OND seasonal rainfall over the lake region.

Keywords: Rainfall; NAO; OND; Kenya

Introduction

Rainfall is the climatic factor of maximum significance for the east African countries. Kenya's economy is mainly dependent on rain-fed agriculture making it vulnerable to the impacts of climate variability [1,2]. Global oceans play a significant role in the determination of weather and climate over various regions of the world [3]. Through currents, oceans transfer heat, moisture, salt, momentum, and nutrients not only from one location to another, but also from upper to deeper layers, absorbing up to 90% of the total heat [4].Therefore studying the dynamics of the oceans, just like the dynamics of the atmosphere, is essential for an in-depth understanding the global and regional weather and climate regimes.

Kenya is bound within latitude 5°S–5°N and longitude 34°–42°E (Figure 1). The country is bordered by Ethiopia to the north, Somalia to the east, Uganda to the west and Tanzania to the south. The country shares Lake Victoria on the west with Uganda and Tanzania. The presence of this lake plays a significant role in rain pattern and the climatology of western Kenya, by providing moisture during evaporation [5,6].

Rainfall over Kenya and the most parts of the larger east Africa exhibits a large spatiotemporal variability [7-9]. The spatial variation has been attributed to the existence of large scale systems and local systems such as inland water bodies which include Lake Victoria, Tanganyika and Kyoga, among others and a complex topography [2,10,11]. The two main rainfall regimes experienced in the region are March-May (MAM) season; 'long rains' and October-December (OND); 'short rains' [12-15]. The two rain seasons coincide with the passage of the Inter Tropical Convergence Zone (ITCZ) over equator that lags behind the overhead sun by about a month, while the wet seasons are separated by two dry spells from June to August and January to February [15]. The OND rainfall exhibits higher intraseasonal and interannual variability as compared to long rains [16,17].

Atlantic Ocean plays an increasingly significant role in the systems that result in rainfall activities in many parts of the world, particularly Europe [3]. However, few studies have been done to understand the contribution of the Atlantic Ocean, unlike other oceans such as Pacific and Indian [18,19], on the rainfall variability in Kenya. The variance explained by the existing weather predictors in Kenya is still low [20] and thus there is still need to search for more predictors. Most studies have constantly linked rainfall variability to Indian Ocean Dipole (IOD), El-Niño southern oscillation (ENSO), Madden-Julian Oscillation, Quasi-Bienniel Oscillation and other Teleconnections [12,21-33]. These results suggest that ENSO modulates rainfall over much of the African continent; [31] showed that ENSO explains less than 40% of the rainfall variability within East Africa. The 'wet' and 'dry' phases of ENSO correspond to 'cold' and 'warm' phases, respectively, in the low-latitude Atlantic and Indian Oceans. According to Bahaga et al. [21], the Indian Ocean, especially the western pole of the IOD plays a dominant role for the prediction skill of OND rainfall, whereas Seas Surface Temperatures (SSTs) outside the Indian Ocean have a minor influence.

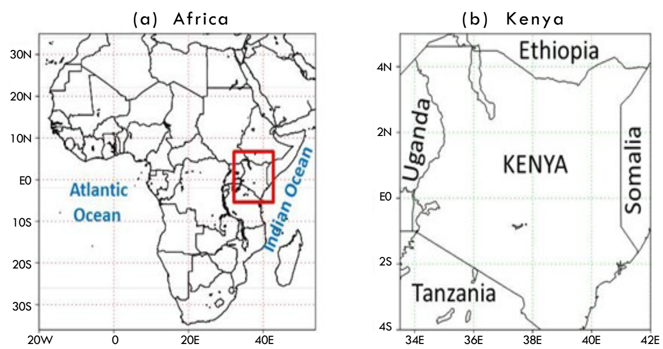

Figure 1: Area of study (a) the continent of Africa (Kenya is enclosed by the rectangle in red color), (b) Kenya.

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This study introduces another possible teleconnection that has not been linked to this variability over Kenya. Over the east Africa region of study, the source of moisture that results in rainfall includes Indian Ocean, Lake Victoria and the Congo forest [34-36]. The study hypothesizes that the NAO index enhances the interaction of the westerlies and the Indian Ocean.

The North Atlantic Oscillation (NAO) has been recognized more than 85 years ago as one of the key patterns of atmospheric variability in the Northern Hemisphere [37,38]. NAO Index is the normalized pressure difference between the subtropical high at about 30 °N (the Azores) and low-pressure zone at 60°S (Iceland). The grid points for the calculation of NAO index are; the Icelandic low, (65°N/20°W –60°N/15°W) and the Azores High, (40°N/30° W-35°N/25°W) (Figure 2). It forms a large-scale sea saw of atmospheric mass between the two regions [3].The positive NAO index phase indicates a stronger than usual subtropical high-pressure center and a deeper than normal low. The negative NAO index phase shows the reverse of the above [39].

Between 1960 and 1990, Hurrel [3] studied NAO Index values and observed that the positive NAO winters occur when there is a very large pressure difference between the Azores and the Iceland. This resulted in more and stronger winter storms crossing the Atlantic and traveling in the northeasterly direction [40,41]. It is our supposition that this circulation enhances the south easterlies in the southern hemisphere that then pumps moisture from Indian Ocean to east Africa. Conversely in negative NAO conditions shows a weak subtropical high and a weak Icelandic low.

Several studies [3,42,43] have in the recent past established links between the NAO Index and rainfall in Western Europe and the Mediterranean basin. Little has been done over Kenya and east Africa at large to investigate the relation. This study therefore attempts to relate rainfall performance over western Kenya to the North Atlantic Oscillation with a view to check if there is any relationship between the two. This could help improve the prediction of the rainfall for this region.

Data and Methodology

The study uses, monthly rainfall values for selected stations in western Kenya, monthly NAO Index values. The data is obtained from Kenya Meteorological Service (KMS), National Centre for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalyses upper-air data (2.5° grid) [44]. The data utilized is for fifty years; 1960-2010.

The zonal and meridional winds, relative humidity and temperature used to examine moisture transport and wind anomalies are those of ERA-interim, gridded at 0.75° resolution [45].

Trend and spatial analysis is used to study the distribution of rainfall over the region while statistical methods were used to summarize the data. Correlation (Equation 1) is used to determine the relationship between the NAO index values and the rainfall amounts.

$$R_{xy} = \frac{\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2 \cdot \frac{1}{n}\sum_{i=}^{n}\left(y_i - \bar{y}\right)^2}} \quad (1)$$

Where; R_{xy} is the correlation coefficient between rainfall and NAO Index, n is the sample size, X_i is the rainfall figures, Y_i is the NAO Index figures, $\bar{x}$ is the mean rainfall, $\bar{y}$ is the mean NAO Index . Standardized precipitation index is used to identify wet and dry years. For this index, the dry and wet years are classified as expressed in Equation 2.

$Z > 1$ for wet year, $1 \leq Z \leq$ -1in normal rainfall years and Z < -1 for dry year (2)

where; Z are standard normalized rainfall values. The computed correlation values were tested for statistical significance using the student-t- test as shown in Equation 3

$$t_{n-2} = r\sqrt{\frac{n-2}{1-r^2}} \quad (3)$$

Where; *t* is the value of the student-*t*-test, n is the sample size, *r* is the correlation being tested.

Results and Discussions

Figure 3 presents the annual cycle of rainfall over the Kenya. The figure depicts the bimodal rainfall pattern; showing the 'long rain' season in MAM and the 'short rain' season in OND. The rainfall

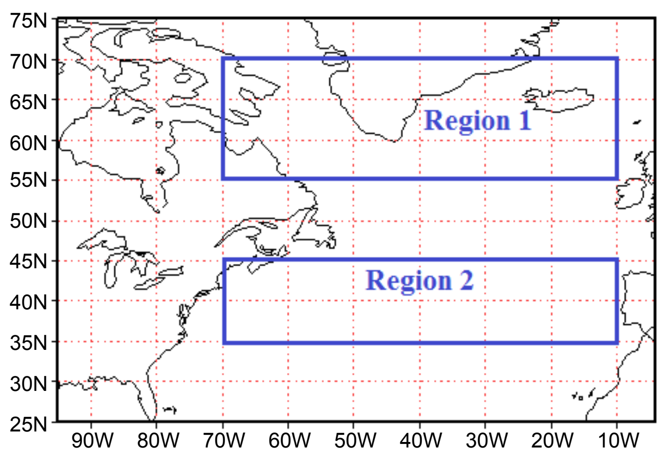

Figure 2: Position of Northern Atlantic Ocean Oscillation regions.

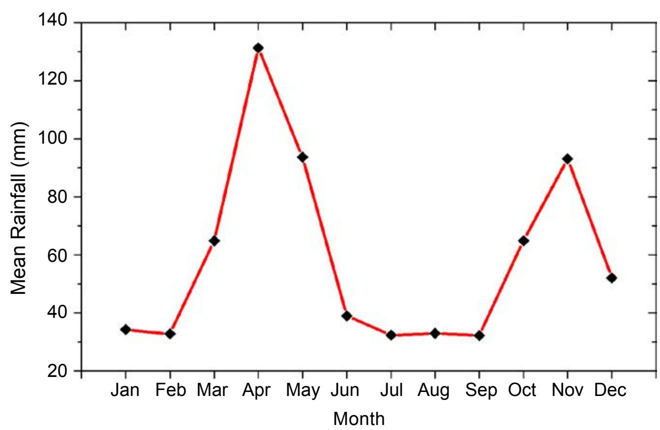

Figure 3: Monthly total rainfall variability for selected stations, 1960-2010.

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peaks are observed in April and November during MAM and OND respectively. The rainfall amount is more in the MAM season as compared to that of the 'short rain' season; OND. These observations are in agreement with previous studies [12-14,46].

Figure 4 presents a time series of the rainfall anomalies. The wet years were found to be 1961, 1963, 1967, 1977, 1982 and 1997 while the dry years were 1970, 1975, 1987, 1996 and 1998.

The magnitude of extreme weather events; drought and flood is presented using the anomaly index, summarized in Table 1. The wettest year during the period of study is 1961 followed by 1997 while the driest is 1998 followed by 1996.

Figure 5 presents low level wind anomaly flow over east Africa during wet years and during dry years.

In order tounderstand the circulation mechanisms associated with the observed dry and wet years in the study period and to provide possible explanations, we examine moisture transport (MTR), wind patterns, geopotential height and temperature at low level (850 hpa).

Results from MTR analysis reveal that during wet years (Figure 5a), the region was dominated by moisture convergence at 850 hpa, as opposed to dry years (Figure 5b) which exhibit moisture divergence in most parts of the region. These results agree with a study by Ogwang et al. [47] which associated moisture convergence with higher rainfall amounts, whereas moisture divergence at low level results into low rainfall amount in the region, hence dry years.

Analyses of geopotential height and temperature at 850 hpa show that during wet years (Figure 6a), there exists a wide spread negative anomaly of geopotetial height. This is associated with lower than normal pressure at low level, which results in low level convergence and leads to vertical stretching (rising motion). This favors convection, hence wet years. There is a general negative anomaly of temperature in the region at 850 during this period. Dry years on the hand (Figure 6b) are characterized by positive anomaly of geopotential height over the region. This is associated with higher than normal pressure at low level, which is associated with divergence. Divergence at low level results in vertical shrinking that supresses precipitation due to subsidence [47], hence dry years.The region is dominated bywide spread positive anomalies of temperature at 850 hpa during dry years. The predorminat moisture flow over the entire country during both rainfall seasons is easterly. This indicates that the contribution of moisture from Congo

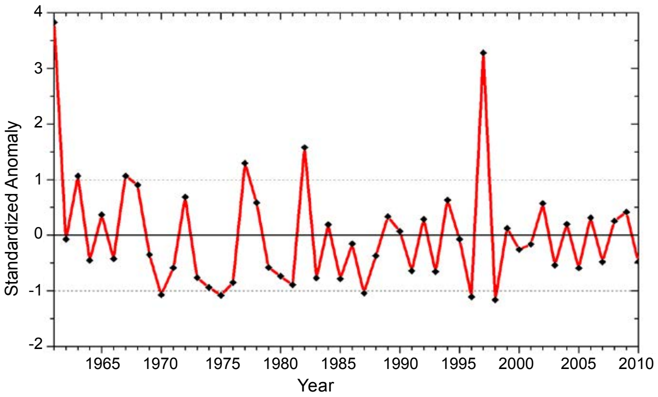

Figure 4: Wet and dry years over Western Kenya, 1960-2010 (Dry and Wet years have anomaly of ≥1 and ≤ -1 respectively).

Wet Year	Anomaly	Dry Year	Anomaly
1961	3.82	1970	-1.07
1963	1.07	1975	-1.08
1967	1.07	1987	-1.04
1977	1.29	1996	-1.11
1982	1.58	1998	-1.16
1997	3.28		

Table 1: Wet and Dry years' standardized anomalies of rainfall.

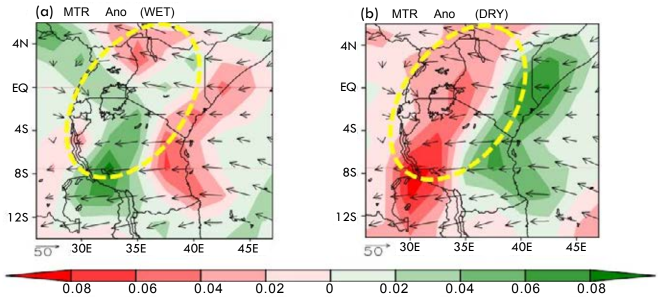

Figure 5: The mean composite OND water vapor/moisture transport (MTR) anomaly at 850 hpa in g kg−1ms−1 (a) wet years (b) dry years. The shaded regions indicate moisture convergence (positive) and moisture divergence (negative), and the vectors show water vapour.

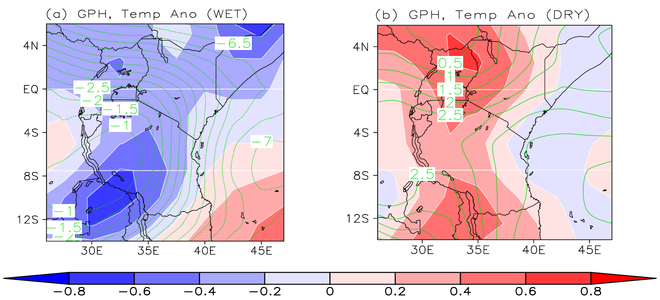

Figure 6: The mean composite OND geopotential height anomaly (GPH, contour) in gpm and temperature anomaly (Temp, shaded) in °C at 850 hpa (a) wet years (b) dry years.

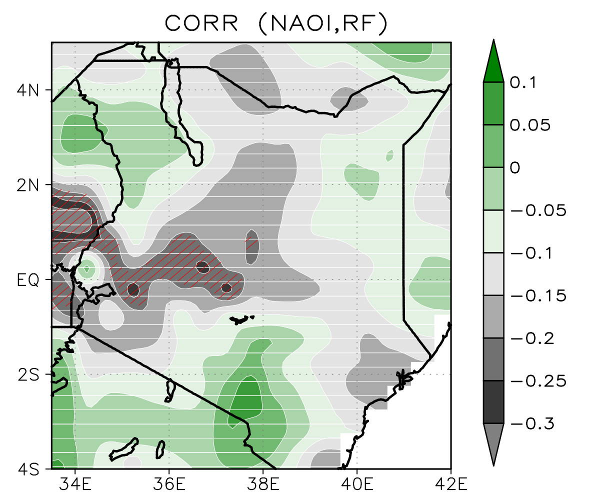

Figure 7: Correlation between period NAOI and OND rainfall over Kenya during 1961-2010period (the hatched area represents significant correlation between the two variables at 90% significance level).

forest is only significant to rainfall over Kenya, especially over werstern Kenya during weak easterlies over the country.

Figure 7 presents the correlation (Corr) between NAO index (NAOI) and OND rainfall (RF) over years; 1961-2010.Generally, the Corr (NAOI vs RF) is -0.13 when the area average rainfall is correlated with NAOI.

The correlation between NAOI and OND rainfall over Kenya is generally low and highly variable in space ranging from negative to positive correlation. The results show that a very small area in the western part of the country exhibits significant correlation between NAOI and OND rainfall.

Conclusions and Recommendations

The MAM season contributes higher amount of rainfall to the observed total rainfall in Kenya as compared to the OND seasonal rainfall. The wettest year during the period of study is 1961 while 1998 is the driest. The dry years are characterized by divergence in low levels while the wet years are characterized by low level convergence.

The correlation of the North Atlantic Ocean Oscillation Index for the entire season is negative and weak. The correlation is insignificant at 90% significance level over most areas of the country with an exception of the western region; surrounding Lake Victoria. The study thus does recommend the adoption of NAOI as a predictor of OND seasonal rainfall over the entire country with the exception of the Lake Victoria region.

Conflict of Interest

The authors declare there is no potential conflict of interest of whatsoever.

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